TRAVEL TIME AND CONCURRENT-SCHEDULE CHOICE: RETROSPECTIVE VERSUS PROSPECTIVE CONTROL

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Six pigeons were trained on concurrent variable-interval schedules in which two different travel times between alternatives, 4.5 and 0.5 s, were randomly arranged. In Part 1, the next travel time was signaled while the subjects were responding on each alternative. Generalized matching analyses of performance in the presence of the two travel-time signals showed significantly higher response and time sensitivity when the longer travel time was signaled compared to when the shorter time was signaled. When the data were analyzed as a function of the previous travel time, there were no differences in sensitivity. Dwell times on the alternatives were consistently longer in the presence of the stimulus that signaled the longer travel time than they were in the presence of the stimulus that signaled the shorter travel time. These results are in accord with a recent quantitative account of the effects of travel time. In Part 2, no signals indicating the next travel time were given. When these data were analyzed as a function of the previous travel time, time-allocation sensitivity after the 4.5-s travel time was significantly greater than that after the 0.5-s travel time, but no such difference was found for response allocation. Dwell times were also longer when the previous travel time had been longer.

Key words: choice, concurrent schedules, travel time, overmatching, punishment model, key peck, pigeons

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Two experiments have shown that imposing a travel time between responding on the two alternatives in a concurrent variable-interval (VI) VI schedule increases preference for the higher reinforcer-rate alternative. The effect can be described in terms of the generalized matching relation (Baum, 1974):

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{R_1}{R_2}\right) + \log c, \qquad (1)$$

where B denotes counts of behavior, R denotes counts of reinforcers, and the subscripts denote the two alternatives. The parameter a is called sensitivity to reinforcement, and measures the change in behavior allocation proportional to changes in reinforcer allocation. Log c is termed bias, and reflects any choice-affecting variables that are not equal between the two alternatives.

Increasing travel time increases a, the sensitivity to reinforcement. This was first shown by Baum (1982), who trained pigeons on a two-key concurrent VI VI schedule, and, in various conditions, changed the distance the

subjects had to travel, and the difficulty of moving, between the alternatives. He found a trend towards overmatching (a in Equation 1 greater than 1.0) as travel requirements were increased. Baum concluded that a punishment model (de Villiers, 1980; Farley, 1980; Farley & Fantino, 1978), in which the degree of punishment depended on the cost of travel (in the sense of work, which was equal between the two directions of travel), could not account for his data. The punishment model for concurrent schedules that Baum considered was

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{R_1 - \alpha S_1}{R_2 - \alpha S_2}\right) + \log c. \quad (2)$$

The variables are the same as in Equation 1, with S_1 and S_2 being the number of punishers delivered for the two alternative responses and α being a scaling parameter that relates one punisher to one reinforcer. In the travel-time situation, α should be 1.0 because the nature of the punisher is simply loss of reinforcers during travel.

Davison and McCarthy (1988) reanalyzed Baum's (1982) data and suggested that they were consistent with a punishment model which assumed that the punishment, S, acting on performance in each alternative, arose from the reinforcers lost on changing over to

the *other* alternative. Thus, the punishment S_1 for Alternative 1 was the number of reinforcers per session lost traveling from Alternative 1 to Alternative 2. This number will be the travel time from alternative i to alternative j, t_{ij}, multiplied by the reinforcer rate in alternative j. The model is written

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left[\frac{R_1 - t_{12}\left(\frac{R_2}{T_2}\right)}{R_2 - t_{21}\left(\frac{R_1}{T_1}\right)}\right] + \log c. \quad (3)$$

The expression R_i/T_i is the local rate of reinforcement on an alternative, so that this expression multiplied by the travel time is the estimated number of reinforcers lost on the transition from one alternative to the other. Travel-time punishment therefore arises from a time in which reinforcers from the next alternative cannot be obtained, and the "intensity" of the punishment is a function of the duration of the travel time and the reinforcer rate in the next alternative. Davison (1991) investigated a range of both equal and unequal fixed-interval travel times using switching-key concurrent VI VI schedules. With equal travel times, behavior allocation to the higher reinforcer-rate alternative became more extreme as travel time was increased from 0 s to 10 s, but did not show a significant increase between 10 and 20 s. The data were a good fit to Equation 3.

More recently, Temple, Scown, and Foster (1995) applied the model offered by Davison (1991) to hens' responding on concurrent VI VI schedules as a function of the changeover-delay requirement (Herrnstein, 1961). It has often been found (e.g., Silberberg & Fantino, 1970) that response ratios during the changeover delay are either insensitive, or even have a negative relation, to reinforcer ratios, but that response ratios following the changeover delay have a strongly positive relation (*a* greater than 1.0 in Equation 1) to reinforcer ratios. Temple et al. (1995) showed that when the reinforcer-loss model was applied to post-changeover-delay responding, it provided an excellent description of the data with no free parameters.

The purpose of the present experiment was to validate experimentally an ordinal im-

plication of the punishment model for the effects of travel suggested by Davison (1991). To do this, we arranged two different travel times, 4.5 and 0.5 s, with the next travel time discriminatively signaled (Part 1) or not signaled (Part 2). Assuming that the stimuli related to travel time were discriminated, we should find two quantitatively different performances (log response and time ratios) in the presence of the two signals. The punishment model for travel predicts the directional difference in preference that should occur: Behavior allocation should be more extreme when a longer travel time is signaled than when a shorter travel time is signaled. The data we collected also allowed us to ask whether behavior allocation was affected by the previous, rather than the next, travel time.

The experiment commenced with a set of conditions (Part 1) in which one travel time was always 4.5 s and the other one was 0.5 s, and discriminative stimuli (either the left or the right switching key available) signaled the next travel time. In the second set of conditions (Part 2), the next travel time was not signaled (both switching keys were always available and operative). In both parts of the experiment, the value of the next travel time was selected randomly.

METHOD

Subjects

Six homing pigeons, numbered 51 to 56, were maintained at 85% ± 15 g of their free-feeding body weights. The subjects were not naive at the start of the experiment, and immediately before the experiment started had worked on 27 conditions in which signaled travel times were varied. These conditions included equal 2-s travel times and travel times summing to 20 s.

Apparatus

The experiment was conducted in two environments. The initial environment was a sound-attenuating experimental chamber fitted with an exhaust fan to mask external noise. The chamber was 340 mm high, 310 mm wide, and 340 mm deep. Three response keys, 20 mm in diameter, 50 mm center to center, and 260 mm from the grid floor, were set on one wall of the chamber. A magazine

aperture, which was 50 by 50 mm, was situated beneath the center key and 130 mm from the floor. During reinforcement, all keylights were extinguished, and the hopper containing wheat was raised and illuminated for 3 s. The center (main) key was illuminated red or green according to which of the concurrent schedules was in effect. The side keys could be illuminated yellow and acted as the switching keys.

In the home-cage environment, each subject was housed in a cage 375 mm high, 370 mm wide, and 370 mm deep. On one wall was an interface panel on which were located four pecking keys (20 mm diameter). They were 70 mm apart and 220 mm from a wooden perch (20 mm from the floor and 100 mm from the interface) in front of the panel. The keys required about 0.1 N for operation. Also on the panel was a magazine aperture (40 mm by 40 mm), located 60 mm above the perch. During reinforcement, all keylights were extinguished, and the hopper containing wheat was raised and illuminated for 3 s. The left three response keys were used in the experiment. Of these keys, the center (main) key was illuminated red or green according to which of the concurrent schedules was in effect. The keys on each side of this key could be illuminated yellow and acted as the switching keys. In the home-cage environment, the pigeons could see and hear other pigeons working on other experiments, but no personnel entered the experimental room while the experiments were running.

Procedure

At the start of each session, the center (main) key was randomly lit red or green, and the color of this key signaled which of the two VI schedules was in operation. Pecks on the center key were occasionally followed by 3-s access to the hopper containing wheat. One of the two side keys, which acted as changeover keys, was lit yellow, and the location of the lit changeover key signaled which of the two travel times (0.5 or 4.5 s) would occur on switching from the current VI schedule component. Pecking a switching key resulted in the main and switching keys being extinguished, and responses on all keys becoming ineffective, for the travel time. After this time, the next main-key stimulus and schedule were available, and one of the two

Table 1

Sequence of experimental conditions, the probability that a reinforcer was arranged in the red alternative (the probability of reinforcement for the green component was the complement of that for red), the number of sessions in each condition, and the part of the experiment to which each condition contributed. In Part 1, the location of the switching keys signaled whether the next travel time was 4.5 s or 0.5 s. In Part 2, both switching keys were always illuminated and active. The arranged overall probability of reinforcement per second was .0333 throughout.

Condition	p (rft) red	Part	Sessions
1	.8	1	24
2	.5	1	23
3	.2	1	30
4	.7	1	23
5	.3	1	36
6	.3	1	31
7	.3	2	24
8	.8	2	22
9	.2	2	22
10	.7	2	34
11	.5	2	41
12	.8	1	22

switching keys (and next travel times) were selected randomly. Following a reinforcer, the same main key and switching key were presented again.

Over all conditions of the experiment, reinforcers were arranged every 30 s on average by interrogating a probability gate set at .0333 every 1 s. When a reinforcer was arranged in this way, it was then allocated to the red or green alternative according to a defined probability (Table 1). A reinforcer arranged in this way remained available until taken, and no further reinforcers could be arranged until it was taken. The concurrent schedules were thus dependently arranged (Stubbs & Pliskoff, 1969). The schedules ran at all times except during reinforcement, so reinforcers could be arranged, but not taken, during the travel times.

Sessions ended in blackout after 50 reinforcers had been delivered or after 2,500 s, whichever came sooner. All experimental conditions and data collection were arranged using a remote IBM PC-compatible computer running MED-PC® software. In both environments, the subjects were given training sessions consecutively according to subject number, starting at about 7:30 a.m. each day. In the chamber environment, birds were fed mixed grain sufficient to maintain their des-

ignated body weights immediately after each session. In the home-cage environments, all birds were fed when Bird 56 had completed its session.

Part 1 of the experiment (Conditions 1 to 6 and 12) followed the above procedure. Conditions 1 to 5 were carried out in the experimental chamber, and Conditions 6 to 12 were carried out in the home cages. Condition 6 was a replication of Condition 5, and Condition 12 was a replication of Condition 1, with the latter conditions arranged in the home-cage environment. Part 2 of the experiment (Conditions 7 to 11) used the same general procedure in the home-cage environment, but both side keys were available and illuminated, and pecking either changed the schedule and associated stimulus on the center key. In this way, no indication of the next travel time was given.

Conditions were changed when the data had reached a defined stability criterion. For this criterion, the first 10 sessions after a condition change were ignored. Then, starting with Sessions 11, 12, and 13, relative response rates (responses on the red key divided by total session responses) were calculated for each session. In overlapping sets of three sessions, these data were assessed for monotonic trends. When the data had failed to show a monotonic trend on three groups of three sessions, performance for that subject was taken as stable. When this criterion had been met for all 6 subjects, the experimental condition was changed for all subjects. Thus, at least 15 sessions were required for stability. The numbers of sessions actually arranged in each condition are shown in Table 1.

The time at which every event (response, reinforcer, and switch) occurred was collected. The data reported here were summed over the last five sessions of each condition, and are shown in the Appendix.

RESULTS

Before commencing the analysis proper, we need to consider the conditions conducted in the home-cage environment that replicated those in the chamber environment: Condition 6 replicated Condition 5, and Condition 12 replicated Condition 1. Figures 1, 2, and 4 (to be described more fully below) show the data from the home-cage replication condi-

tions for comparison with the data from the original chamber conditions. In no case was there any evidence that the data from the home-cage environments were systematically different from those collected in the chamber. We shall, therefore, take these two sets of data as entirely equivalent, and all subsequent analyses use both the original and the replication data.

Two analyses of the data from Part 1 (signaled travel times) were carried out: In the first analysis, log red/green response- and time-allocation ratios were analyzed according to Equation 1 as a function of log obtained reinforcer ratios. This analysis was done separately according to whether the next signaled travel time was 0.5 or 4.5 s. In the second analysis, the data were analyzed in the same way, but separately as a function of what had been the duration of the previous travel time. The response- and time-allocation data from Part 2 (unsignaled travel times) were analyzed only as a function of the previous travel time. The results of these analyses are shown in Table 2, and response-allocation data for these three analyses are graphed in Figures 1 to 3.

As Table 2 and Figure 1 show, the average response-allocation sensitivity to reinforcement in Part 1 in the presence of the signal for the 4.5-s travel time (1.71) was greater than that in the presence of the signal for the 0.5-s travel time (1.07). This directional difference was shown for all 6 subjects (binomial $p < .05$). For all 6 subjects, time-allocation sensitivities to reinforcement in the presence of the signal for the 4.5-s travel time ($M = 1.23$) were greater than those in the presence of the signal for the 0.5-s travel time ($M = 1.05$). This result was therefore again significant on a binomial test at $p < .05$. The intercepts to the fitted lines were usually close to zero, apart from Bird 54, and were not significantly different for the two travel times.

The second analysis of the Part 1 data focused on the previous travel time rather than the signaled next travel time. The relations between log response and log obtained reinforcer ratios are shown in Figure 2. For response allocation, sensitivity to reinforcement following a 4.5-s travel time averaged 1.43, and sensitivity after a 0.5-s travel time averaged 1.52. On a binomial test, these were not significantly different at $p = .05$. The inter-

Table 2

Fits of Equation 1 for all subjects in both parts of the experiment. In Section A of this table, log response- and time-allocation ratios were fitted with the data divided according to whether the next travel time was 4.5 s or 0.5 s. In Section B, these data were fitted according to whether the previous travel time was 4.5 s or 0.5 s. Standard errors of estimates are given for both the estimated slope (*a* in Equation 1) and estimated intercept (log *c*). %VAC is the percentage of the data variance accounted for by the fits.

	4.5-s travel time					0.5-s travel time				
Bird	Slope	*SE*	Log *c*	*SE*	%VAC	Slope	*SE*	Log *c*	*SE*	%VAC
A: As a function of next travel time										
Part 1										
Response allocation										
51	1.46	0.14	−0.10	0.12	95	0.84	0.22	−0.00	0.27	75
52	1.48	0.14	−0.03	0.11	96	0.71	0.11	0.06	0.13	89
53	1.71	0.14	0.05	0.11	97	0.79	0.19	0.07	0.27	78
54	1.71	0.16	0.19	0.12	96	0.62	0.17	0.11	0.22	73
55	1.78	0.11	−0.02	0.08	98	0.78	0.19	0.06	0.24	77
56	2.09	0.22	0.02	0.13	95	0.35	0.08	0.08	0.10	81
Time allocation										
51	1.02	0.06	−0.04	0.08	98	0.75	0.20	0.07	0.26	73
52	1.16	0.18	0.04	0.17	90	0.66	0.20	0.10	0.23	69
53	1.26	0.10	0.02	0.11	97	0.65	0.15	0.05	0.21	80
54	1.17	0.10	0.11	0.11	96	0.66	0.16	0.04	0.21	77
55	1.39	0.12	0.05	0.10	97	0.71	0.16	0.03	0.20	80
56	1.37	0.09	0.02	0.09	98	0.42	0.09	0.06	0.12	82
B: As a function of previous travel time										
Part 1										
Response allocation										
51	1.23	0.11	−0.05	0.11	96	1.37	0.12	−0.10	0.15	96
52	1.27	0.13	0.01	0.11	95	1.23	0.11	−0.02	0.13	96
53	1.50	0.11	0.08	0.10	97	1.48	0.10	0.06	0.14	98
54	1.38	0.10	0.19	0.09	98	1.56	0.14	0.13	0.19	96
55	1.49	0.08	−0.01	0.06	99	1.68	0.16	0.01	0.20	96
56	1.72	0.19	0.03	0.14	94	1.79	0.22	0.04	0.28	93
Time allocation										
51	0.91	0.09	−0.00	0.12	95	1.05	0.11	−0.06	0.14	95
52	0.98	0.12	0.06	0.14	93	1.12	0.19	0.06	0.22	88
53	1.15	0.08	0.06	0.09	98	1.11	0.07	0.01	0.10	98
54	0.99	0.06	0.13	0.08	98	1.23	0.11	0.08	0.14	96
55	1.19	0.06	0.03	0.07	99	1.36	0.14	0.06	0.18	95
56	1.14	0.10	0.03	0.12	96	1.33	0.08	0.04	0.11	98
Part 2										
Response allocation										
51	1.39	0.14	0.05	0.11	97	1.28	0.13	0.08	0.14	97
52	0.92	0.13	−0.04	0.15	94	0.82	0.21	−0.09	0.24	83
53	1.42	0.17	−0.04	0.13	96	1.15	0.13	−0.06	0.14	96
54	0.97	0.19	−0.08	0.19	90	1.02	0.15	0.05	0.16	94
55	1.46	0.12	−0.04	0.08	98	1.26	0.08	−0.01	0.08	99
56	1.28	0.07	−0.06	0.06	99	1.14	0.08	−0.06	0.08	99
Time allocation										
51	1.28	0.08	0.02	0.07	99	1.27	0.11	0.02	0.13	98
52	1.28	0.07	0.05	0.06	99	1.27	0.13	−0.02	0.15	97
53	1.38	0.13	−0.02	0.10	97	1.01	0.06	−0.05	0.07	99
54	0.99	0.14	−0.05	0.14	94	0.96	0.10	0.07	0.11	97
55	1.29	0.10	−0.01	0.08	98	1.13	0.05	0.04	0.05	99
56	1.17	0.03	0.07	0.03	100	1.06	0.06	0.06	0.06	99

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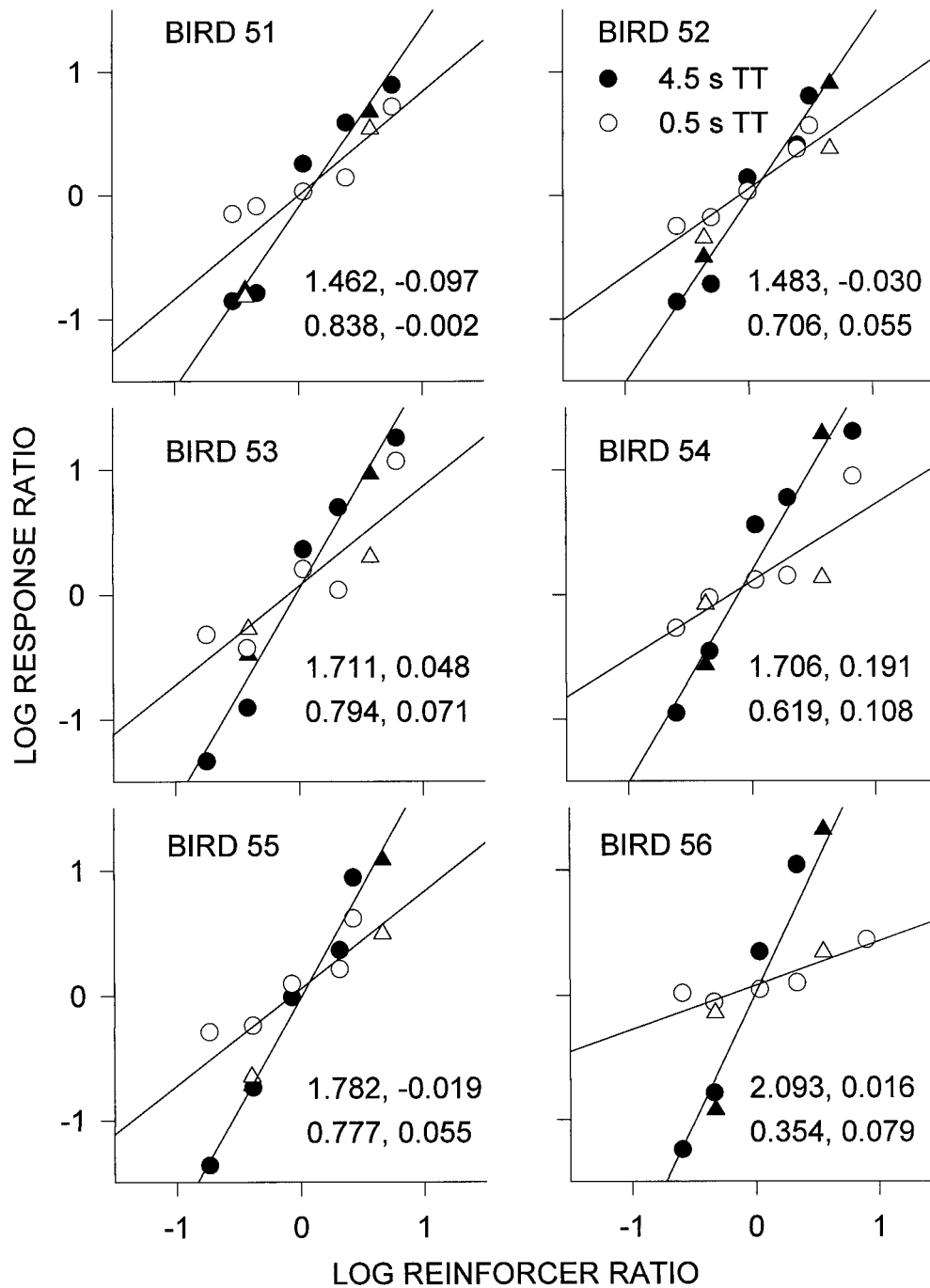
PART 1: NEXT

Fig. 1. Part 1: log (red/green) response ratios plotted as a function of obtained log reinforcer ratios when the next travel time signaled was 0.5 s and when it was 4.5 s. Triangular symbols show the data from replicated conditions, filled symbols indicate 4.5-s travel times, and open symbols indicate 0.5-s travel times. The slopes and intercepts of the fitted lines are shown, the upper pair being for the signaled 4.5-s travel time and the lower pair being for the 0.5-s travel time. The straight lines (Equation 1) were fitted by the method of least squares to all data shown.

PART 1: PREVIOUS

Fig. 2. Part 1: log response ratios plotted as a function of obtained log reinforcer ratios when the previous travel time was 0.5 s and when it was 4.5 s. Triangular symbols show the data from replicated conditions, filled symbols indicate 4.5-s travel times, and open symbols indicate 0.5-s travel times. The slopes and intercepts of the fitted lines are shown, the upper pair being for the 4.5-s travel time and the lower pair being for the 0.5-s travel time. The straight lines were fitted by the method of least squares to all data shown.

cepts to the fitted lines were also not significantly different and were all close to zero. The results for time-allocation measures were similar, with neither sensitivities nor intercepts being significantly different according to the previous travel time.

Comparing estimated response-allocation sensitivity values for these first two analyses, all 4.5-s next-travel-time sensitivities were greater than 4.5-s previous-travel-time sensitivities ($p < .05$), and all 0.5-s next-travel-time sensitivities were smaller than 0.5-s previous-travel-time sensitivities ($p < .05$). For time-allocation sensitivity, exactly the same was true for the 4.5-s travel-time sensitivities ($p < .05$), but for 0.5 s, only five of the six next-travel-time sensitivities were smaller than those from the previous-travel-time analyses ($p > .05$).

In Part 2, when no signals for the next travel time were given, an analysis of performance as a function of the next travel times is inappropriate; therefore, the only analysis conducted was in terms of the previous travel time. For response allocation, sensitivity after a 4.5-s travel time averaged 1.24, and after a 0.5-s travel time sensitivity averaged 1.11. On a binomial test, these values were not significantly different at $p = .05$, and the same was true for the intercepts, which were all close to zero. However, all time-allocation sensitivities were greater after a 4.5-s travel time ($M = 1.23$) than after a 0.5-s travel time ($M = 1.12$), which is significant on a binomial test at $p < .05$. The difference between the sensitivities was small, and it is possible that this result is a Type I error. There was no significant difference between the intercepts, which were again close to zero.

The fits of Equation 1 (Table 2, Figures 1 to 3) were generally very good, with high percentages of data variance accounted for and small standard errors of parameter estimates.

Comparing response- and time-allocation sensitivities (Table 2) for the analysis of the Part 1 data as a function of the next travel time, all response-allocation sensitivities for the 4.5-s travel time ($M = 1.71$) were greater than the corresponding time-allocation sensitivities ($M = 1.06$), significant at $p < .05$ on a binomial test. However, this difference was not significant in the presence of the signal for the 0.5-s travel time (Ms = 1.07 and 1.05). The analysis of the Part 1 data according to the previous travel time showed that re-

sponse-allocation sensitivity was significantly greater than time-allocation sensitivity (binomial $p < .05$) following both the 4.5-s and the 0.5-s travel times (Ms = 1.43 and 1.06 for 4.5 s and 1.52 and 1.20 for 0.5 s). In Part 2, there were no significant differences on a binomial test between response- and time-allocation sensitivities (Ms = 1.24 and 1.23 for 4.5 s and 1.11 and 1.12 for 0.5 s).

Figures 4 and 5 show dwell, or interchange-over, times in Parts 1 and 2, respectively. These data were averaged over all 6 subjects, but are representative of the performance of each individual. In Part 1, when the next travel time was signaled, dwell times were consistently longer in the presence of the signal for the 4.5-s travel time than in the presence of the 0.5-s travel time at all relative reinforcer rates. However, when the data were analyzed according to the previous travel time, there were no systematic differences in dwell times between previous 4.5-s or 0.5-s travel times. In Part 2, when the next travel times were not signaled, dwell times after 4.5-s travel times were consistently greater than those following 0.5-s travel times.

DISCUSSION

Sensitivity to reinforcement (*a* in Equation 1) is affected by travel time between the choice alternatives (Baum, 1982; Davison, 1991). With zero travel time, sensitivity is usually about 0.8 to 0.9 in concurrent exponential VI VI schedules, but when travel time is increased to 10 s, sensitivity increases to about 1.7 (Davison, 1991). Davison offered a model (Equation 3) for this finding that was based on the subtractive theory of punishment (de Villiers, 1980; Farley, 1980; Farley & Fantino, 1978). In this model, travel between alternatives is a punisher inasmuch as time spent traveling leads to the loss of reinforcers. More specifically, the reinforcer value of being at Alternative 1 is decreased by the number of reinforcers lost from Alternative 2 when the subject switches from Alternative 1 to Alternative 2. The model therefore implies prospective control of choice: Performance on the current alternative is controlled by the loss of reinforcers from the next alternative when the subject leaves the current alternative. A retrospective mechanism was entertained by Baum (1982): The value of a patch
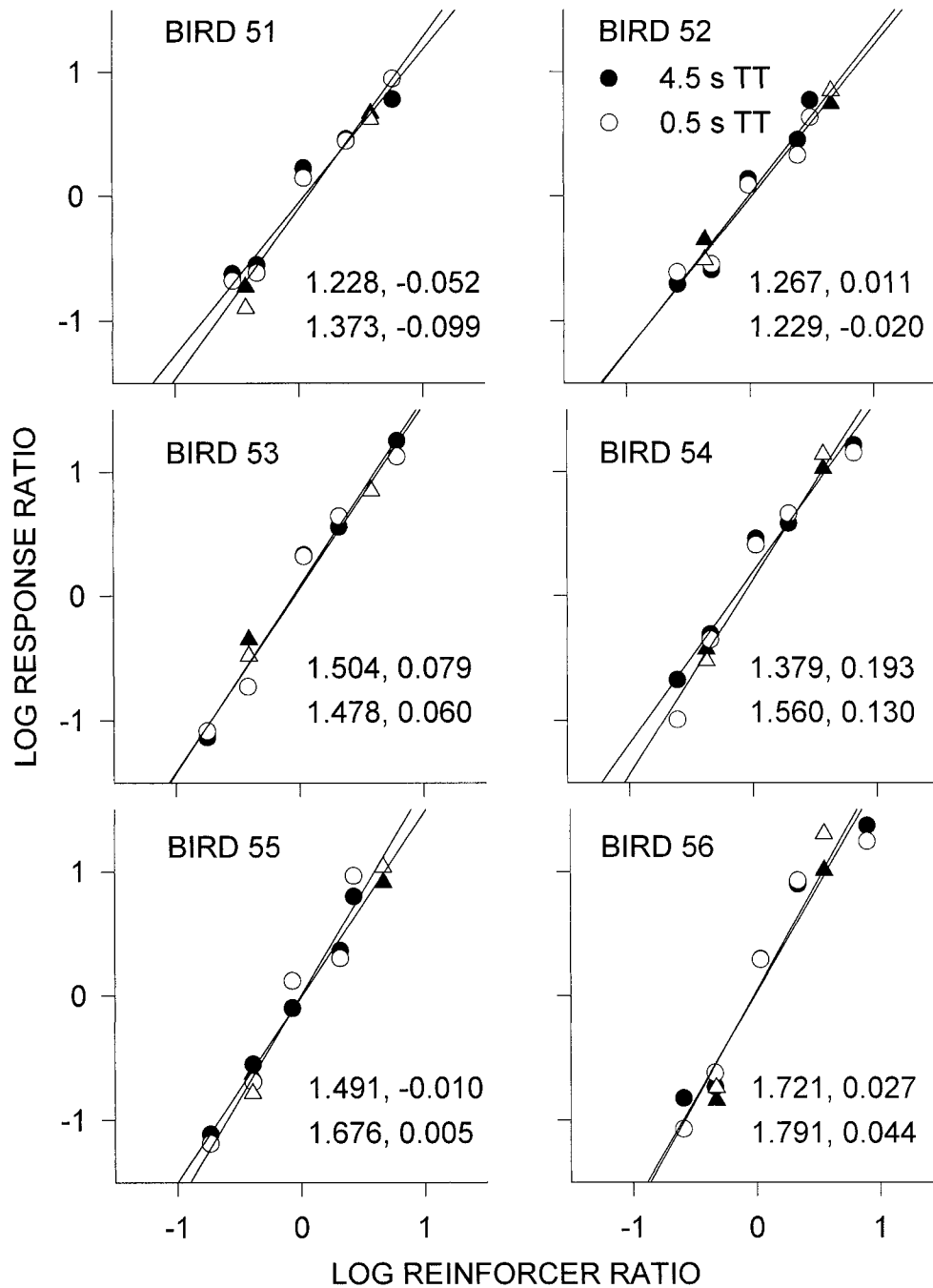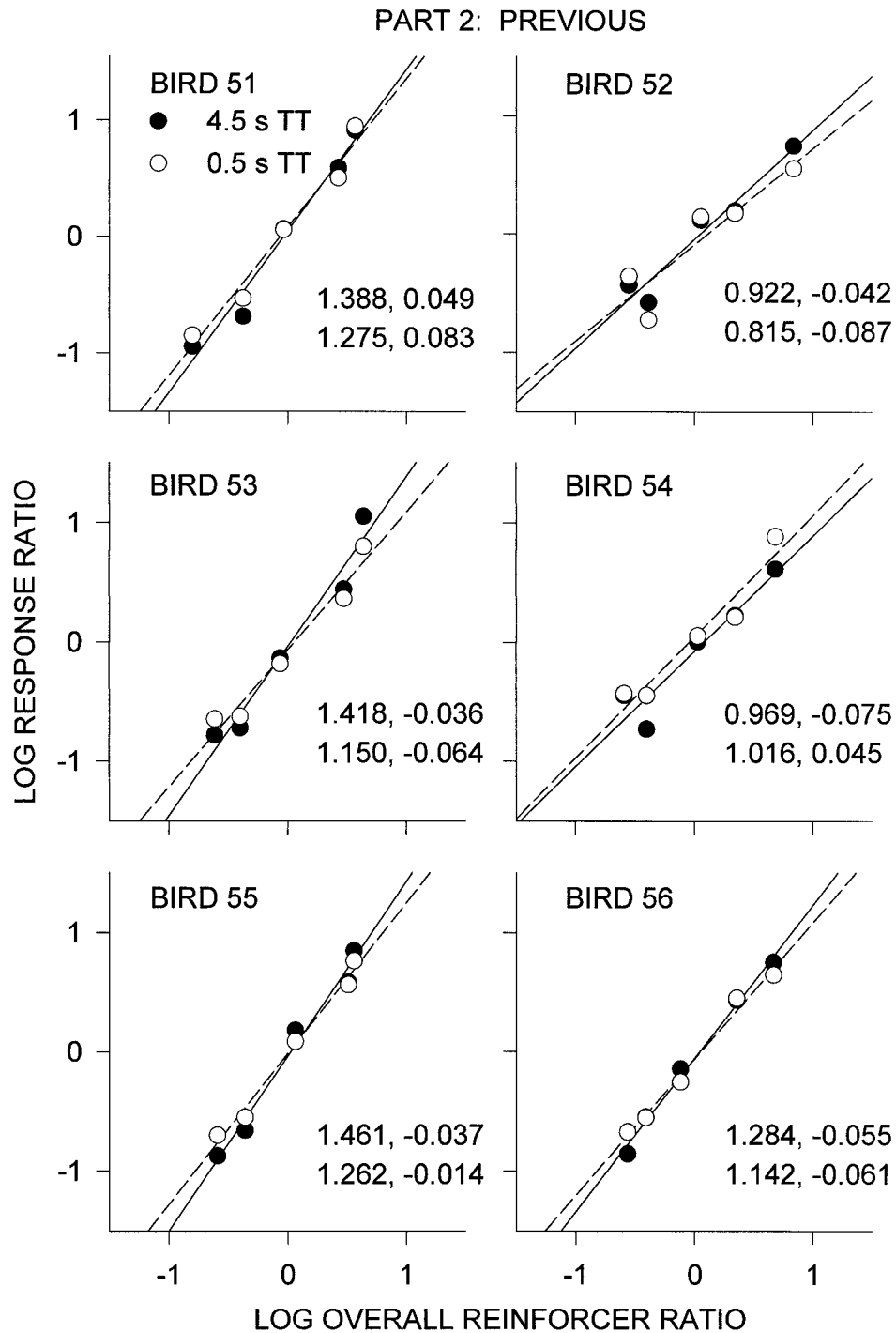
PART 2: PREVIOUS

Fig. 3. Part 2: log response ratios plotted as a function of obtained log reinforcer ratios when the previous travel time was 0.5 s and when it was 4.5 s. The slopes and intercepts of the fitted lines are shown, the upper pair being for the 4.5-s travel time and the lower pair being for the 0.5-s travel time. The straight lines were fitted by the method of least squares.

4.5-s NEXT TRAVEL TIME

0.5-s NEXT TRAVEL TIME

4.5-s PREVIOUS TRAVEL TIME

0.5-s PREVIOUS TRAVEL TIME
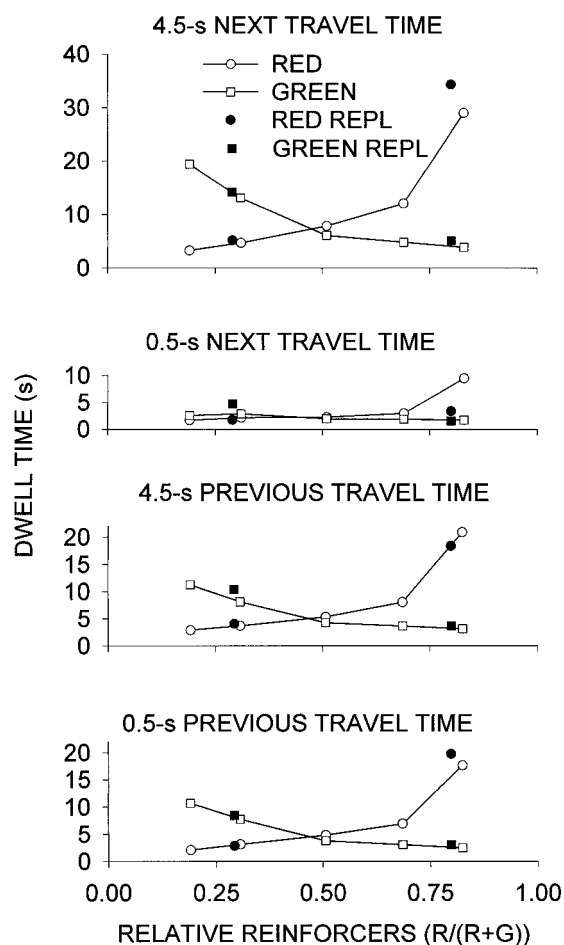
RELATIVE REINFORCERS (R/(R+G))

Fig. 4. Group average dwell (interchangeover) times in Part 1 of the experiment when the next travel time was signaled. The two upper graphs show the data for 4.5-s and 0.5-s travel times analyzed according to the next travel time. The lower two graphs show the data analyzed according to the previous travel time. Replications are shown as filled symbols.

PART 2
PREVIOUS TRAVEL TIMES
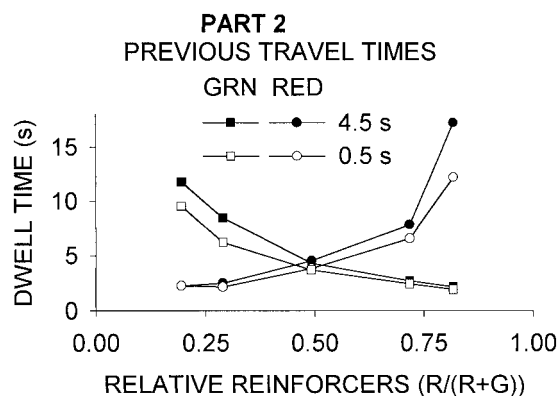

RELATIVE REINFORCERS (R/(R+G))

Fig. 5. Group average dwell (interchangeover) times in Part 2 of the experiment when the next travel time was not signaled. The data are analyzed according to the previous travel time.

is affected by how difficult or punishing it is to enter that patch rather than to leave it. However, Baum showed that this theory did not account for his data.

The approach that Davison (1991) took was to collect a large amount of data using both equal and unequal travel times, and to fit the prospective punishment model to those data. The data fitted the model well, supporting the prospective punishment idea. However, a good data–model fit is achievable with many different quantitative models, and the purported prospective punishment mechanism requires experimental demonstration

also. Thus, in Part 1 of the present experiment, we arranged two different travel times and signaled in each component the next travel time to be arranged. If punishment derives from the reinforcers lost during the next travel time, this procedure will give higher sensitivities to reinforcement when the longer travel time is signaled than when the shorter travel time is signaled, at least if the discriminative stimuli signaling the upcoming travel times are discriminable. We found exactly this result (Figure 1 and Table 2). We also analyzed the same data according to the previous travel time, which was uncorrelated with the next travel time. These analyses gave no significant differences between sensitivities to reinforcement after shorter and longer travel times. Thus, the idea of prospective punishment, rather than retrospective punishment or work, was fully supported.

This result, on its own, does not necessarily support the idea that prospective punishment affects choice in procedures with single travel times that are unsignaled but predictable. It could be that signaling the next travel time changed the locus of control to prospective punishment, and that control was indeed retrospective in single-travel-time procedures. Thus, in Part 2, we arranged the same two travel times, but with no discriminative stimulus signaling the next travel time. Analyzing these data as a function of the previous travel time, we found no significant difference in sensitivity between previous short and long

travel times on response measures, but we did find that time-allocation sensitivities were greater after a 4.5-s travel time than after a 0.5-s travel time. The mean difference in sensitivities (0.11) was, however, small. More to the point, the failure to find a significant difference in response-allocation sensitivities in Part 2 clearly cannot explain the large increases in response-allocation sensitivity between 0-s and 10-s travel times reported by Davison (1991). Nevertheless, the present data do not completely rule out the idea that some retrospective control might apply to time allocation when the next travel time is unsignaled.

The mean response and time sensitivities when the signaled 4.5-s travel time was arranged in Part 1 (responses, 1.7; time, 1.23) are close to the values reported for the 10-s travel time by Davison (1991), which were 1.7 and 1.35, respectively. Given that Davison found that these values did not change when a 20-s travel time was instituted (1.67 and 1.30, respectively), the function relating sensitivity to travel time is clearly steep between 0-s and 5-s travel times. Indeed, the response and time sensitivities found here for a 0.5-s travel time (1.07 and 1.05, respectively) are slightly larger than those for a 0-s travel time (0.96 and 0.84) reported by Davison.

Dwell times (Figures 4 and 5) also supported the idea that the value of an alternative is affected by the travel time to the next alternative. Subjects spent considerably longer at an alternative when the next travel time was 4.5 s than when it was 0.5 s, but there was no differential effect of the last travel time (Figure 4). When the next travel time was not signaled in Part 2, there was an effect of the previous travel time: When this had been longer, subjects spent more time on the next alternative. This result was unexpected, but it seems to be consistent with the generalized matching results from Part 2, which showed greater time-allocation sensitivities after 4.5-s than after 0.5-s travel times (Figure 3). These effects, though, are small compared with those produced by signaling the next travel time. Because there were no equivalent effects on response-allocation sensitivity, this seems to be an effect on time allocation only. Further, because we found no effects of the previous travel time when the next travel time was signaled, the effect of previous travel time

on subsequent time allocation seems to appear only when the next travel time is unsignaled and hence is unknown. The model (Equation 3), when cast in time-allocation rather than response-allocation terms, cannot predict this effect, and we can offer no good reason why response- and time-allocation measures of choice differ in this way.

Overall, the present results provide generally good support for the model proposed by Davison (1991) and the view that performance on concurrent alternatives is punished by the loss of reinforcers when subjects travel from that alternative. The degree of punishment associated with responding on the higher reinforcer-rate alternative is less (because it depends on the reinforcer rate in the lower reinforcer-rate alternative) than the punishment associated with the lower reinforcer-rate alternative (because that depends on the higher reinforcer-rate alternative). This effect is embodied in Equation 3, and naturally leads to overmatching on concurrent VI VI schedules when travel times are arranged. The small effects of previous travel time on time allocation and dwell time when the next travel time is not signaled require further experimentation, and may indicate problems with the model used here.

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APPENDIX

Numbers of responses, time spent responding in seconds, and number of reinforcers obtained on the red and green alternatives according to whether the next travel time was short (0.5 s) or long (4.5 s) over the last five sessions in each condition. In Conditions 1 to 6 and 12, the next travel time was signaled, and in the remainder of the conditions, it was not signaled.

| | | Main-key responses | | | | Time allocation (s) | | | | Reinforcers | | | |
| | | Red | | Green | | Red | | Green | | Red | | Green | |
Condition		Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short
Bird 51	1	4,164	1,324	529	252	4,192	1,230	968	276	138	75	21	16
	2	2,541	912	1,404	843	2,441	673	1,957	619	81	50	71	48
	3	674	572	4,785	804	1,011	442	4,146	682	31	26	131	62
	4	3,385	905	869	646	2,765	863	1,294	576	108	69	44	29
	5	649	572	3,966	697	1,370	830	3,036	687	38	41	119	52
	6	312	238	1,822	1,565	844	428	2,932	2,235	32	36	99	83
	7	2,232	585	472	169	3,799	662	879	199	141	57	33	19
	8	569	520	2,491	1,930	691	690	2,812	2,282	31	43	98	78
	9	2,979	2,526	352	295	3,004	2,628	472	375	104	93	31	22
	10	322	262	2,728	1,922	446	361	3,995	2,917	20	14	131	85
	11	1,668	1,547	451	451	2,208	1,989	678	668	102	80	36	32
	12	1,007	947	869	824	1,493	1,362	1,333	1,275	61	59	71	59
Bird 52	1	2,717	1,669	424	452	3,823	2,484	572	482	106	83	24	37
	2	2,721	883	1,947	814	2,143	968	2,155	887	69	55	71	55
	3	568	536	4,127	946	887	834	3,444	1,013	27	25	139	59
	4	2,515	1,663	978	697	2,434	1,961	1,879	896	91	87	39	33
	5	792	525	4,108	790	1,518	824	3,512	884	42	41	115	52
	6	329	423	1,038	931	1,099	711	2,266	2,056	40	36	72	102
	7	3,075	464	382	194	5,900	599	709	267	168	37	26	19
	8	280	275	1,137	1,224	606	650	2,012	2,223	33	40	85	92
	9	764	800	177	154	4,468	4,566	403	291	113	100	18	13
	10	506	543	1,187	1,386	525	617	2,437	2,754	26	29	90	105
	11	621	720	412	453	2,079	2,368	928	930	82	90	42	36
	12	808	803	558	621	1,542	1,557	1,027	1,014	65	67	61	55
Bird 53	1	3,541	1,800	194	152	5,029	2,678	662	384	143	72	14	21
	2	2,415	743	1,042	461	2,979	931	1,924	703	83	47	71	49
	3	251	202	5,426	418	619	375	6,810	620	13	25	175	37
	4	4,298	353	859	321	5,294	507	1,660	474	128	40	45	36
	5	380	370	3,042	981	1,192	693	5,128	1,522	33	36	123	58
	6	606	333	1,825	622	1,582	705	3,310	1,364	40	30	108	72
	7	2,534	242	274	121	6,599	686	1,161	329	145	44	32	18
	8	223	307	1,033	1,437	587	721	1,919	2,830	34	37	76	103
	9	1,447	1,827	174	198	3,610	4,346	545	540	107	93	19	27
	10	257	237	1,230	1,368	554	520	2,506	2,953	27	22	90	111
	11	1,088	1,063	456	381	2,147	2,181	846	752	90	97	34	29
	12	459	528	685	730	1,047	1,253	1,442	1,671	51	65	62	72
Bird 54	1	4,440	1,585	217	178	5,520	1,871	704	235	143	74	14	19
	2	2,458	583	681	443	2,487	543	1,439	490	78	51	60	61

APPENDIX

(Continued)

| | | Main-key responses | | | | Time allocation (s) | | | | Reinforcers | | | |
| | | Red | | Green | | Red | | Green | | Red | | Green | |
Condition		Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short
	3	489	226	4,339	417	844	249	3,752	568	27	22	126	75
	4	2,960	458	497	323	2,709	502	996	344	109	56	52	33
	5	655	421	1,856	446	1,224	492	2,011	613	40	38	99	73
	6	860	320	3,135	381	1,694	346	4,507	529	45	29	125	51
	7	5,171	263	266	193	6,086	293	669	241	166	31	30	23
	8	297	275	1,170	1,109	596	535	1,767	1,647	41	30	100	79
	9	2,241	2,062	386	393	2,338	2,103	428	414	113	94	22	21
	10	427	477	1,321	1,147	519	654	1,856	1,623	22	29	104	95
	11	720	709	418	437	1,190	1,188	577	578	83	89	44	34
	12	769	779	678	760	1,106	1,239	1,095	1,292	59	70	55	66
Bird 55	1	3,762	741	428	179	4,556	891	657	262	129	53	45	23
	2	2,060	533	2,102	425	2,176	587	2,142	527	63	52	74	61
	3	247	182	5,699	353	488	222	5,586	432	17	22	165	46
	4	2,643	711	1,137	433	2,638	726	1,295	477	111	58	39	42
	5	716	333	3,872	574	1,172	374	3,876	676	38	35	122	55
	6	344	158	1,795	703	1,294	259	3,107	991	47	25	105	73
	7	3,673	379	303	121	6,692	615	839	223	164	40	23	21
	8	513	530	2,012	2,215	829	735	2,048	2,318	45	31	83	91
	9	2,263	1,804	328	301	2,964	2,434	471	440	108	88	26	28
	10	364	403	2,281	2,318	535	654	2,933	2,929	24	27	103	96
	11	1,908	1,385	472	407	2,872	2,105	761	707	109	82	26	33
	12	993	1,129	794	762	1,426	1,610	1,172	1,060	60	74	55	61
Bird 56	1	4,609	286	136	103	7,262	523	496	133	196	26	22	6
	2	2,744	446	1,231	399	3,069	664	2,217	613	72	58	68	52
	3	302	334	5,266	321	978	385	4,781	493	22	29	146	53
	4	5,781	281	525	223	5,213	425	1,260	404	135	36	40	39
	5	761	278	4,602	316	1,388	406	4,470	441	45	34	130	41
	6	460	208	3,831	289	1,618	459	6,234	551	40	40	133	37
	7	3,739	254	178	115	6,657	636	1,071	358	157	38	27	28
	8	341	330	1,312	1,071	898	867	2,509	1,926	33	37	112	68
	9	1,404	1,354	270	286	2,836	2,859	463	444	98	107	24	20
	10	240	262	1,433	1,517	667	571	2,181	2,219	28	18	86	82
	11	721	888	257	323	2,517	3,071	914	930	74	98	42	34
	12	603	586	977	887	1,501	1,630	1,956	1,729	48	60	78	64